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Experimental and numerical analysis of electrical contact crimping to predict mechanical strength

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Abstract

This work focuses on the modeling of the aeronautical electrical contact crimping process for aircraft applications. Several thousands of crimped contact can be found in an airplane or a helicopter. The crimping process has thus to be mastered precisely in order to avoid expensive repairing and dangerous configurations. Electrical crimping is a plastic deformation process of a contact (component) on a multi-strand wire. All components are highly deformed in order to impose mechanical contact and electrical continuity. The components are very small for the cases studied in this work (0.12 mm diameter wire or 1 mm diameter cylinders). The work has been divided in 3 main steps. First, material characterization is performed in order to identify behavior laws to feed numerical simulations. The challenge is to be able to deal with very small components. The second point is to build an accurate a numerical model of the crimping process. The numerical model is compared with experimental results. Validation is done comparing with both laboratory devices and real crimped assemblies. Finally mechanical strength is studied. The numerical model is used to verify the impact of components' dimensions or crimping condition on the mechanical resistance. Numerical models are also compared to experimental data.

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1. Introduction

Electrical contact crimping could be expected to be well a known and mastered fastening technology while it is studied for a long time, Hayner (1967). In aeronautical applications, non-conforming electrical junction may lead to expensive repairing actions or security problems. It is then important to control the quality of crimping points to avoid bad electrical junctions. This technology is then highly normalized. Checking of conforming properties is leading to tedious, destructive an expensive experimental campaigns. The aim of our work is to develop an accurate computational tool able to simulate the crimping operation and to verify that the configuration obtained is verifying the imposed mechanical tolerance. The developed numerical model will be detailed, as well as the characterization of material properties of the components. The results are then compared to experimental data both in terms of crimping validation configuration and resulting mechanical strength analysis.

2. Material behavior characterization

The first step to feed numerical models is to determine the behavior law associated to the different components. In our case, only two types of components will be considered, the strands composing the cable and the contact.

The strand will be considered as a homogeneous material. The impact of coating will be integrated in this homogeneous law and the friction coefficient between strands and contact. The electrical contact is also considered as homogeneous. Fig. 1 shows the dimensions of the components and can highlight the associated problems.

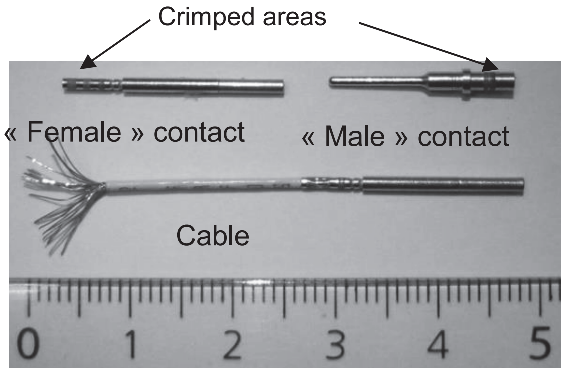

Fig. 1. Size and geometries of the different components.

2.1. Behavior of strands

The tests are performed on a Erichsen tension device. As far as it can be observed on the 0.1 diameter strands, there is no necking during the test. The behavior of strands will be identified through tension tests combined with a excel analysis to obtain parameter of a linear power law (1).

$$\sigma_0 = \sqrt{3K(1 + a\varepsilon_p{}^n)}\,, \tag{1}$$

Where σ_0 is the stress, K the consistency, ε_p the plastic strain, a and n the hardening parameters.

Ink drops are attached to the strands to record real displacement independently from device deflection, loss of rigidity or sliding of the strands in the grips that are often mentioned when dealing with such small specimens. Parameters identified are summarized in Table 1.

Fig. 2. Experimental device for identification of material behaviour of the strands.

2.2. Behavior of the contact

The contact can be considered as a 1.1 mm diameter cylinder. No normalized geometry can thus be extracted from this component. We have then chosen to develop a dedicated test and to use inverse analysis with the software Forge® to identify the behavior law parameters, Ducloux et al. (2013). Both the device and the corresponding computational model can be seen on Fig. 3. Identified parameters of the linear power law (2) are given in table 1 and were identified in Petitprez and Mocellin (2013).

$$\sigma_0 = \sqrt{3K(\varepsilon_0 + \varepsilon_p)^n}, \tag{2}$$

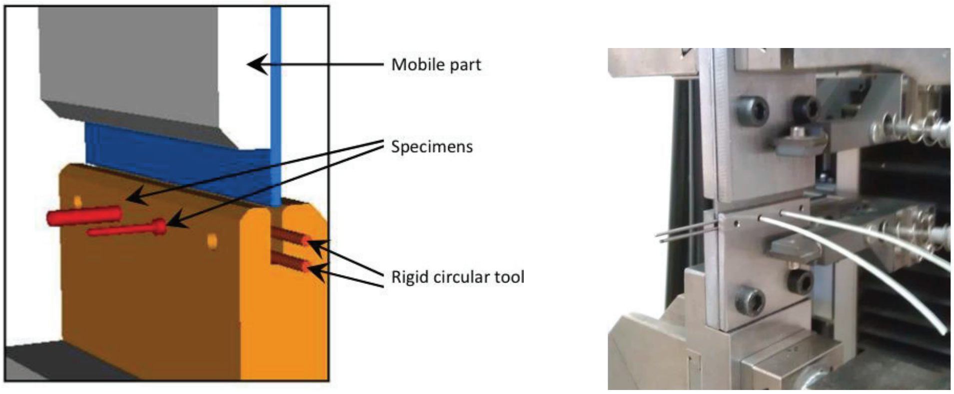

Fig. 3. Experimental device and associated simulation for inverse analysis on contact.

Table 1. Summary of behavior law parameters.

Parameter	K (MPa)	n	ε_0	a	E (MPa)
Strand	115	0.52	-	1.27	50.000
Contact	294	0.28	0.006	-	88.038

3. Numerical models

In order to study mechanical strength of crimped parts junction, two separate models have to be implemented. First the crimping process linking a 19 strands copper cables and a copper cylinder has to be simulated, then the resulting geometries, residual stresses and strains are transported into a tension test model to study the resistance of the mechanical junction.

Several numerical issues have to be overcome to be able to study the mechanical strength of crimped junctions. Taking into account the mechanical history of the assembling process has been demonstrated to be of first importance in the framework of mechanical strength analysis of riveting operations Porcaro et al. (2006), Bouchard (2008), we will then compute as accurately as possible the assembling step. The high number of deformable domains in crimping leads to complex modeling of high deformation in multibody configuration. The numerical software chosen to simulate the problem is Forge® described in Chenot (1989). Based on an implicit formulation using mixed velocity/pressure finite element model, it allows dealing with multi domain contact problems, Pichelin et al. (2001).

3.1. Crimping process

The crimping model is presented in Fig. 4, both initial and final crimped configurations are shown. The strands are maintained using a circular tool representing the sheath and avoiding the non-physical untwisting of the strands. Crimping tools are considered as rigid and crimping depth is determined from experimental crimping tests.

Fig. 4. Initial and final configuration of crimping process computation.

Our model is validated by comparison with an instrumented crimping tool. A good agreement is observed between numerical and experimental results; for example, crimping force is measured on each of the 4 jaws and compared on Fig. 5.

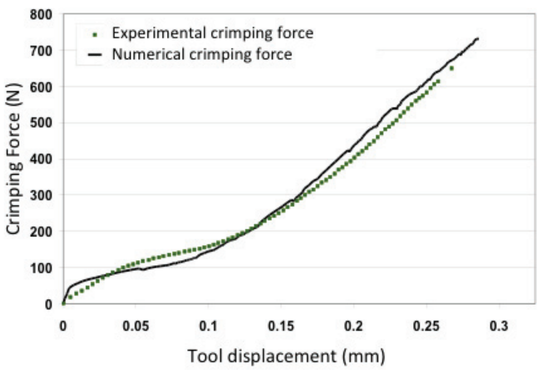

Fig. 5. Comparison of experimental and numerical crimping force.

3.2. Mechanical strength analysis

Mechanical strength analysis is also performed with the software Forge®. Both geometries and mechanical history are transported from crimping simulation to tension one. Additional "tools" are added to model the tension conditions. The computational model is not considering a long enough cable to compare the whole force curves with industrial tension tests. We can only check that the junction is resisting to the maximal admissible force. The computational is predicting a maximal value of he force around 80 N while the industrial threshold is of 60N.

3.3. Influence of the crimping step

To prove the hypothesis that mechanical state coming from the crimping step is important for the mechanical strength analysis, computation taking into account geometry and stress state is compared to one with only geometry. Final tension states are shown on Fig. 6. It can be seen that the cable is not breaking in the same area and the stress level are very different for the two configurations.

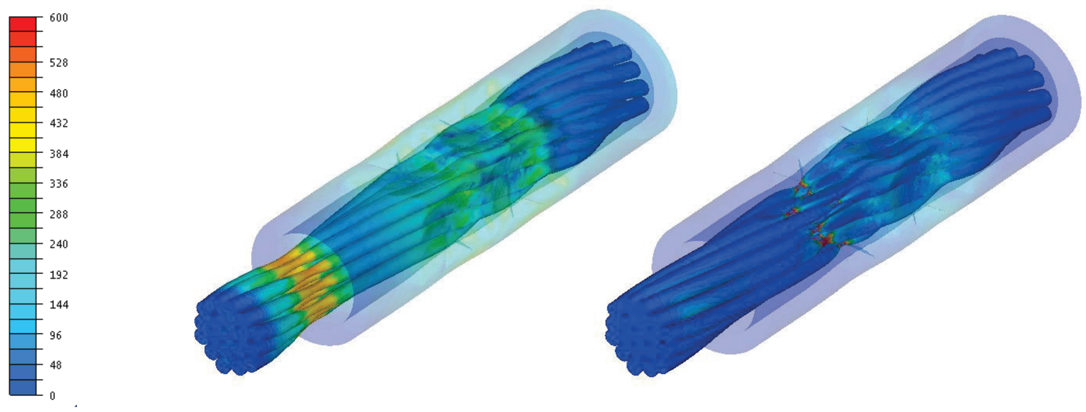

Fig. 6. Final tension configuration taking into account geometry and stress state from crimping simulation (left) and only the geometry (right).

4. Validation strategy

In order to obtain experimental and numerical results on exactly the same configuration, pseudo crimping tests were then performed on academic device described in Fig. 3. Both crimped profiles, crimping force or tension force can be compared between experiments and computation. Tensile forces are shown on Fig. 7. The computational result is of the same order than the experimental ones. Small discrepancies can be observed in the experimental force.

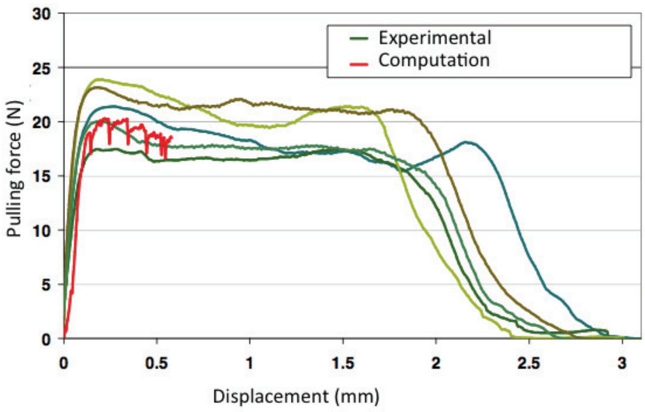

Fig. 7. Comparison of experimental and computational pulling forces.

5. Conclusion

A global experimental and computational study has been presented. It aims in being able to predict the mechanical strength of crimped assembly. Some tests have been performed to identify material behavior of the components. Particular attention has to be paid according to their small size. Then the computational models of crimping and pulling are compared to experimental results. A good agreement is observed. The developed methodology is validated and could be considered for the development of new crimping configuration such as aluminum/copper assembly.

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